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THE METEOROLOGICAL MAGAZINE

October 1963 No. 1095 Vol. 92

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THE METEOROLOGICAL MAGAZINE

Vol. 92, No. 1095, October 1963

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DEVELOPMENT OF THE JET STREAM AND CUT-OFF CIRCULATIONS

By C. J. BOYDEN

Summary.—The changes in the 300 mb flow leading to the development of jet streams are described, and it is found that jet streams in middle latitudes usually occur through deformation of a single baroclinic flow rather than by confluence of two air streams. Working rules are presented for forecasting the development and movement of cut-off highs and lows at the 300 mb level on the basis of the jet-stream pattern and the shape of the 500–300 mb thickness lines.

The development of a jet.—It is not the purpose of this paper to discuss theories of jet-stream development but rather to recognize associated developments which are of use in jet forecasting. It is necessary, however, to make brief references to existing theories because of the sequence of events which they postulate. A theory put forward by Rossby[1] was based on the constancy of absolute vorticity during lateral mixing. This involves a southward increase of relative vorticity culminating in a sharpening of the zonal wind speed profile in middle latitudes. In so far as the jet stream of middle latitudes is concerned this explanation is supported by Palmén.[2] On the other hand Namias and Clapp[3] propounded the confluence theory in which thickness lines and contours become concentrated where cold air from the north is brought to flow beside warm air from further south. The confluence which concentrates the flow results basically from a wave train in one latitude overtaking a wave train in another.

The present study led to the conclusion that, whatever may be the broad-scale mechanism leading to the development of a strong upper wind belt, the final stage in the development of a jet is much as described by the University of Chicago group[4] in 1947. It was found that a jet usually developed through confluence on the east side of an upper ridge or trough but not in the way suggested by Namias and Clapp.[3] In most cases the jet formed within a single amplifying flow, independently of the existence of a confluence with a stream of air of different origin.

An analysis was made of jet streams occurring in four winter months chosen at random. Occasions were noted when jets developed *in situ*, as distinct from those when jets spread downstream or laterally into the area. There were 32 such jets which were located where profiles of the 300 mb wind speed could be drawn. In each case, an estimate was made of where on the profile the trajectory from any upstream split of the airstream should be found. The position of this was then compared with the position of the peak wind speed.

As far as could be ascertained, the confluence of different airstreams was the main cause of one of the 32 peak winds and a contributory cause of three others. Twenty-nine of the 32 jets developed mainly in association with a concentration of thickness lines on the east side of an upper ridge or trough. It is therefore considered that the great majority of jets develop through an intensification of the thermal gradient which accompanies the buckling of the flow pattern as described in the following paragraphs, a second airstream not being involved.

Figure 1 (*a*) depicts a uniform belt of moderate or strong upper winds in which the thickness lines, shown by broken lines, lie along the flow. Figure 1 (*b*) shows the beginning of an oscillation, perhaps associated with upstream cyclogenesis or with the approach of a thermal trough causing a sympathetic troughing of the contours. It is clear from the direction of the wind at A and

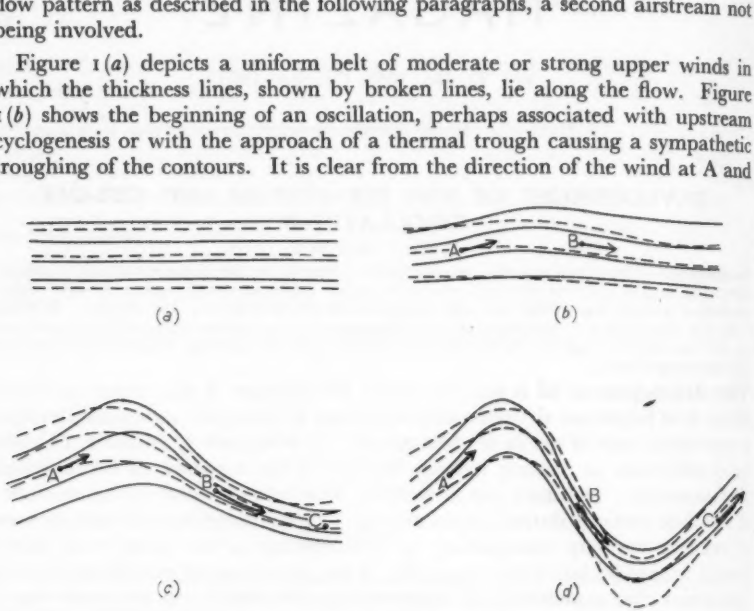


FIGURE 1—THE DEVELOPMENT OF JET STREAMS

——— contours - - - - thickness lines

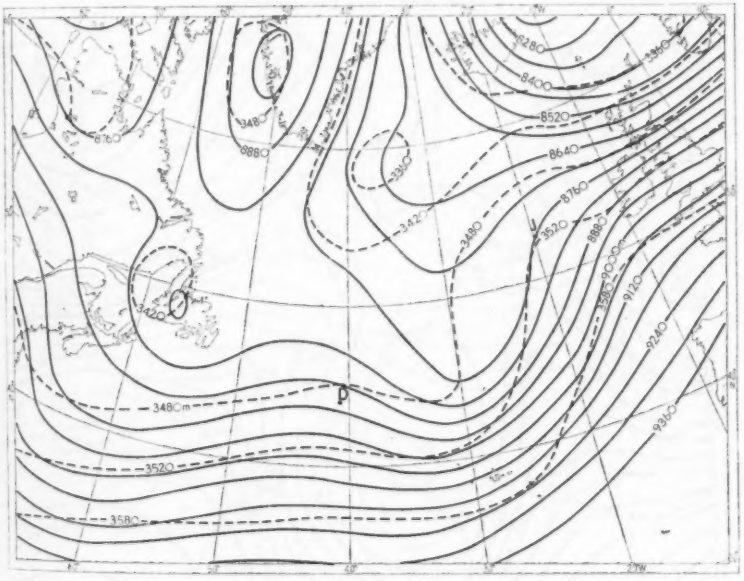
Arrows represent wind at points A, B and C

B that the thickness lines must begin to take up the oscillation, and thermal advection in turn induces an oscillation in the contours, so the development becomes self-generating. The advection across thickness lines is seen to be greater upwind of B than it is at B, so, as shown in Figure 1 (*c*), a concentration of thickness lines develops in the region of B. Thus the thermal ridge and the contour ridge become asymmetrical and remain slightly out of phase. On most occasions the advection of warm air and therefore the rise of 300 mb height are greatest to north-west of B, so the jet at B usually veers. A weakening and backing of this jet are to be expected if the supply of warm air is cut off, and this sometimes occurs when a cold pool or the remnant of one interrupts the flow of warm air. The usual veering of the jet at B backs the thickness lines through C and they become a concentrated band leading to the development of a south-westerly jet at C as shown in Figure 1 (*d*). This process can be perpetuated further, the older jets usually weakening from various causes, but it is more likely that the train of waves will be interrupted by the development of a cut-off low or, less frequently, by a cut-off high.

The 300 mb chart of 0000 GMT on 4 December 1961, reproduced as Figure 2(*a*), shows a typical development. At this time a trough in the longitude of Bermuda was beginning to develop, and 24 hours later (Figure 2(*b*)) there was strong warm advection on the east side of ocean weather station "D", accompanied by a sharpening of the 300 mb ridge. Within a further 24 hours the advective warming had reached ocean weather station "J" and the chart of 0000 GMT on 6 December (Figure 2(*c*)) shows a strong north-westerly jet there. There is clear evidence that this marked increase of wind was a feature of the ridge and followed the arrival of warm air, and there is no evidence that the confluence with the air from Greenland played any part in the development of the jet. On this occasion there was little intensification of the south-westerly wind over Europe, mainly because the north-westerly jet led to the formation of a cut-off low over the Mediterranean.

The chain of events described above is presented without any dynamical explanation but will be recognized as the downwind propagation through the pattern of an intensification and amplification of the flow. This type of pulsation was studied by Rossby[5] and he showed theoretically that such a feature should have a 'group velocity' in excess of the zonal wind speed.

It is not uncommon to find two parallel jets within a few hundred miles of each other. This sometimes occurs ahead of a pair of warm fronts but the jets are more likely to be found on either side of a confluence of two separate airstreams, one jet being associated with a cold front and cyclonic flow, the

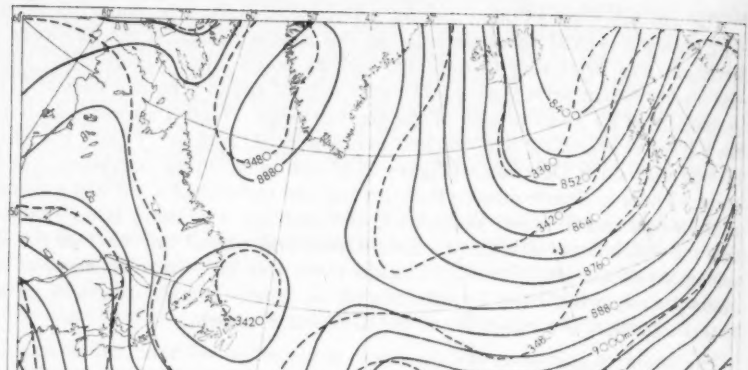


2(*a*) 0000 GMT on 4 December 1961

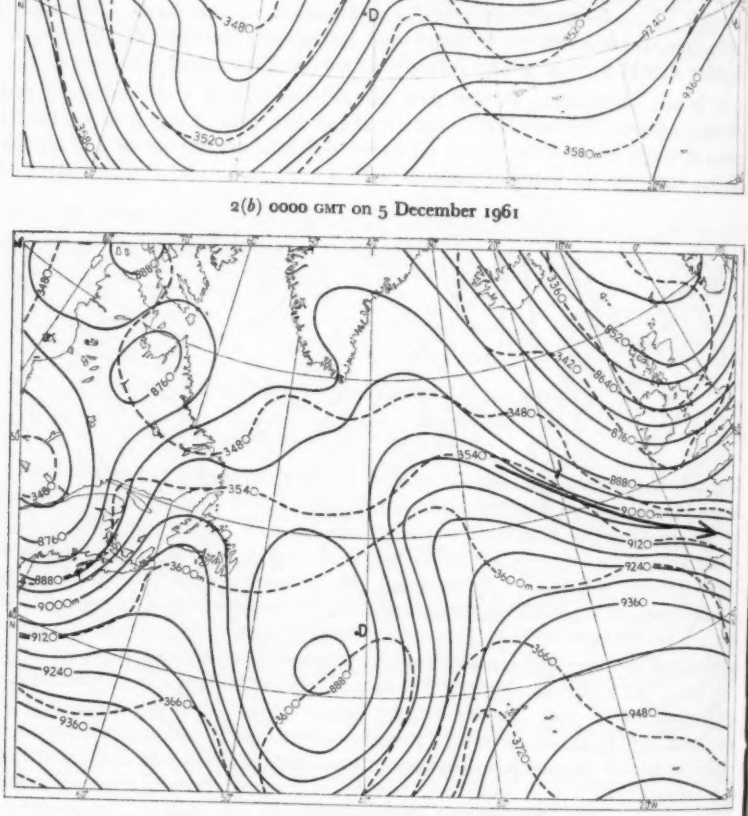
FIGURE 2—THE DEVELOPMENT OF A NORTH-WESTERLY JET IN WARM AIR

——— 300 mb contours ▓ - - - - 500–300 mb thickness

J and D are ocean weather stations.



2(*b*) 0000 GMT on 5 December 1961

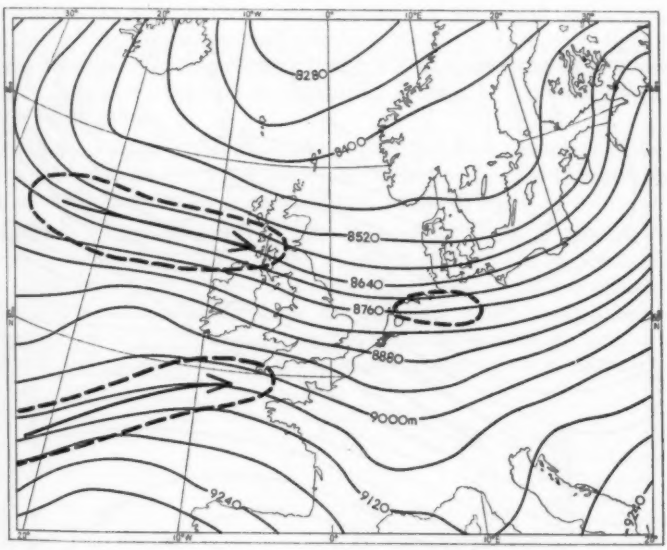


2(*c*) 0000 GMT on 6 December 1961, bold arrow indicates position of jet stream.

FIGURE 2—THE DEVELOPMENT OF A NORTH-WESTERLY JET IN WARM AIR

other with a warm front accompanying an upper ridge. Because of the confluence, the jets probably draw nearer to each other and may eventually be regarded as a single jet produced by the confluence, the true evolution being lost in the process of simplifying the analysis. An example of this is shown in Figure 3. The 300 mb chart for 0000 GMT on 3 December 1961 (Figure 3(*a*)) shows a warm jet approaching south-west England and a cold jet approaching west Scotland. The broken lines show the main 100 knot isotachs, though these are inevitably somewhat uncertain. Twenty-four hours later (Figure 3(*b*)) both jets had propagated downstream and drawn closer to the confluence. By 1200 GMT on 4 December (Figure 3(*c*)) the cold jet had moved quickly to Scandinavia and the warm jet had moved north to the Midlands, so for practical purposes there was now a single jet, though with variations along it of wind speed and probably of height. This amalgamation of jets is favoured by some buckling of the flow but it is more usual for the two to retain their separate identities and move side by side for as long as wind continues at jet speeds.

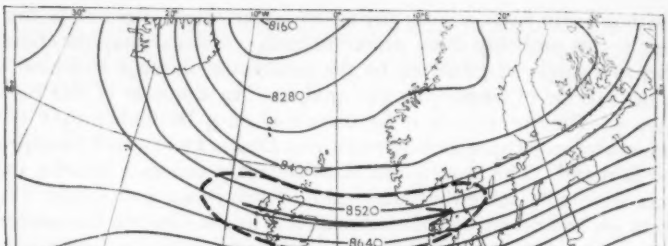
The development of cut-off circulations.—Closed circulations at upper levels are formed in a variety of ways, sometimes by the upward growth of low-level systems and sometimes initially as features of the upper flow. A closed circulation appearing first in the middle or upper troposphere develops when a zonal flow becomes meridional, with the result that there is an increase



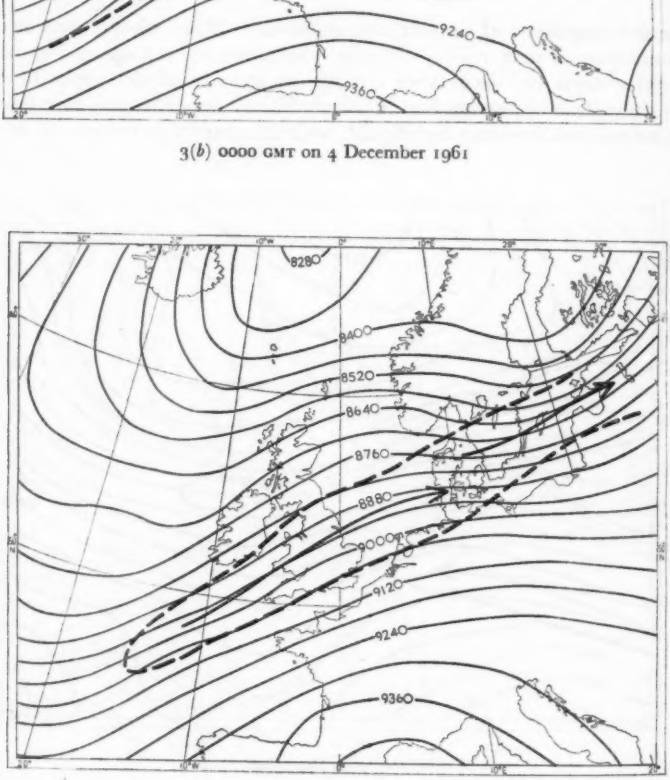
3(*a*) 0000 GMT on 3 December 1961

FIGURE 3—THE AMALGAMATION OF TWO JET STREAMS

——— 300 mb contours ——— ——— 100 knot isotachs
Bold arrows indicate the position of the jet stream



3(*b*) 0000 GMT on 4 December 1961



3(*c*) 1200 GMT on 4 December 1961

FIGURE 3—THE AMALGAMATION OF TWO JET STREAMS

of relative vorticity in low latitudes and a decrease in the north. The mechanism of cut-off circulations is a study with which the name of Palmén,[2,6] is particularly associated. The precursors of cutting-off have long been recognized as a northward surge of warm air and a southward surge of cold air. The following sections are concerned with recognition of the indications that such a surge is about to lead to a closed upper circulation, and the subsequent behaviour of the systems is discussed briefly.

Cut-off highs at the 300 mb level.—The formation of a 300 mb ridge is associated with the northward movement of warm air. The temperature rise at a fixed point is most rapid when the northward movement is due to a jet. The reason for this is not only that the advecting wind is strong, but primarily that a fairly strong upwind temperature gradient usually exists to the right of a jet since the concentrated thickness lines of the jet from a southerly point usually turn away to the right. The transformation of the ridge into an upper high isolates a pool of warm air and the ridge is renewed to south of the detached circulation. A cut-off high may exist without any low-level counterpart, and its importance arises mainly from the diversion of the upper flow and the subsequent effect of this on low-level systems.

In order to determine conditions for cutting-off, a study was made of 300 mb charts over the North Atlantic and Europe during the months October to March from October 1959 to March 1962. An analysis was made of all highs that formed in a region where observations were adequate to decide whether a closed circulation developed. No account was taken of highs which entered the area as closed circulations. A few highs which appeared almost fortuitously through a small change of height in an area of light winds were also disregarded. Highs which lasted for less than 24 hours were treated separately and were regarded as forecasting failures if they conformed with the rules for formation.

In all there were 52 highs, of which 45 persisted for 24 hours or more. All 52 were preceded by jets from some southerly point, so it is reasonable to regard the existence of a jet as necessary for a high to form.

Amplitude of the thermal ridge.—The extent of the northward flow of warm air was noted in terms of the amplitude of the 500–300 mb thermal ridge. This was obtained by measuring, on the thickness line through the jet, the latitude difference between the thermal trough upwind of the jet and the thermal ridge downwind of it, the measurement being made 12 hours before the high appeared. Figure 4 shows the frequency distribution of

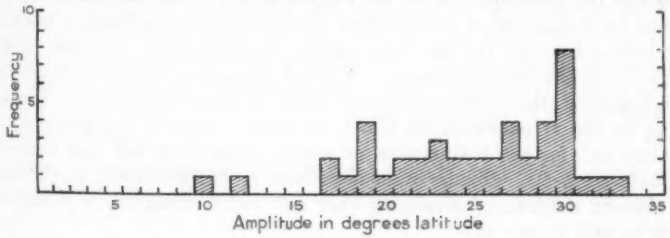


FIGURE 4—DISTRIBUTION OF THERMAL AMPLITUDES 12 HOURS BEFORE HIGHS BECOME CUT-OFF

amplitudes accompanying 44 of the 45 highs (the other already having a warm pool). Only two highs formed following an amplitude smaller than 17° latitude, and this is the only useful information provided by the diagram. The probability of cut-off increases to a well defined peak at an amplitude of 30° latitude but the drop beyond it may indicate no more than a climatological extreme to the amplitude of a thermal ridge.

Shape of the thickness lines.—Since cutting-off is characterized by an abrupt change in shape of both contours and thickness lines it was thought that the 500–300 mb thickness lines would give some indication of its imminence. A distinction was therefore made between ridge-shaped thickness lines and thickness lines which had become bulbous at the top of the ridge. The existence of a thickness bulb was defined by two short sections of a thickness line being parallel to each other on opposite sides of the ridge. The time elapsing between the appearance of a thickness bulb and the appearance of a cut-off high is shown in Table I.

TABLE I—PERIOD BETWEEN FIRST APPEARANCE OF A THICKNESS BULB AND OF A CUT-OFF HIGH

Number of hours between thickness bulb and cut-off high	Number of highs lasting 24 hours or more		Number of highs lasting less than 24 hours	
	With jets from south or east of south	With jets from west of south	With jets from south or east of south	With jets from west of south
0	1	–	–	–
12	11	7	–	1
24	8	10	2	2
36	2	1	–	2
48	1	2	–	–
60	1	–	–	–
Uncertain	–	1	–	–

From this table the following points are noted:

(i) The thickness bulb gave at least 12 hours' warning of cut-off on 50 occasions out of 52.

(ii) Seven of the 52 highs were transient.

(iii) The time lag was greater with jets from west of south and there were more transient highs than with south-easterly jets.

(iv) About 80 per cent of the highs formed 12 or 24 hours after the thickness bulb first appeared.

Direction of the jet.—Longer warning of cut-off can usually be given by forecasting the development of the thickness bulb. Its formation is clearly favoured by a backing of the jet since this produces an advective backing of the thickness lines on the west side of the thermal ridge. Of the 24 south-easterly jets in the second column of Table I, 23 backed in the 24 hours before the high formed, the remaining one showing no direction change. The mean backing on the 11 occasions for which 12 hours' warning was given was 56°, as against 21° for the 8 situations in which a thickness line was bulbous 24 hours before cut-off. On the other hand, the 21 south-westerly jets of column three showed a backing (averaging only 20°) on 8 occasions, a steady direction on 10 and a veer on 3.

There seems to be no doubt that the distinction between south-easterly and south-westerly jets introduced in Table I is related dynamically to cut-off

as well as statistically. An analysis was made of jet directions at the time each of the 45 lasting highs formed, the measurement being made in the strongest part of each jet. The distribution is given in Table II.

TABLE II—FREQUENCY OF UPPER HIGHS IN RELATION TO DIRECTION OF JETS

Jet direction (degrees)	090	100	110	120	130	140	150	160	170	180	190	200	210	220
Number of jets	2	–	–	3	3	11	3	1	1	1	6	8	5	1

The high frequency of south-south-west jets is to be expected though the concentration of directions between 190° and 210° is perhaps surprising. The sharp peak at 140° is of greater interest and it is suggested this may be due to the fact that when a wind backs to about 140° its constant absolute vorticity trajectory no longer gives a continuing eastward movement but intersects itself, the air thus making virtually a closed circulation on the north-east side of the jet.

On 29 of the 31 occasions when the jet backed in the 24 hours before cut-off the backing took place in advance of a trough of which the jet constituted the eastern limb, or in one or two cases in advance of a small low. Thus the first sign that a thickness line is likely to become bulbous may be found upwind of the jet. Besides its effect on thickness lines the trough may be an important feature because the more or less westerly wind behind it may in due course extend round the ridge which forms to south of the cut-off high. There was nevertheless no evidence that this more westerly flow is a feature of the cut-off mechanism.

Conditions for the formation of a cut-off high.—The main conditions favouring the formation of a cut-off high may therefore be summarized as follows:

(i) A jet stream from a southerly point is necessary.

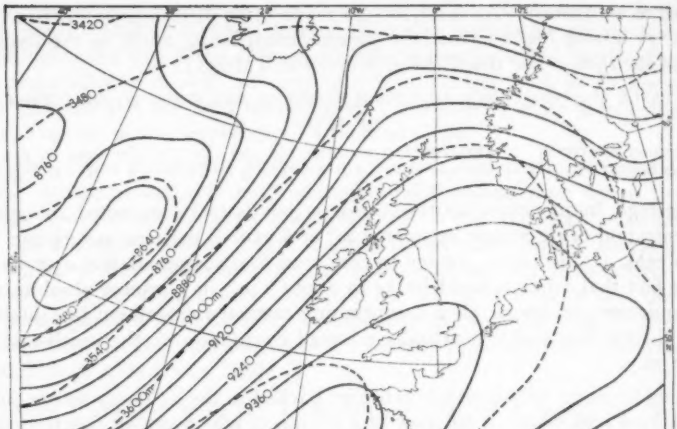
(ii) The amplitude of the ridge in the 500–300 mb thickness line through the jet should be at least 15° of latitude.

(iii) The jet should not veer with time and preferably should back ahead of an upper trough or low.

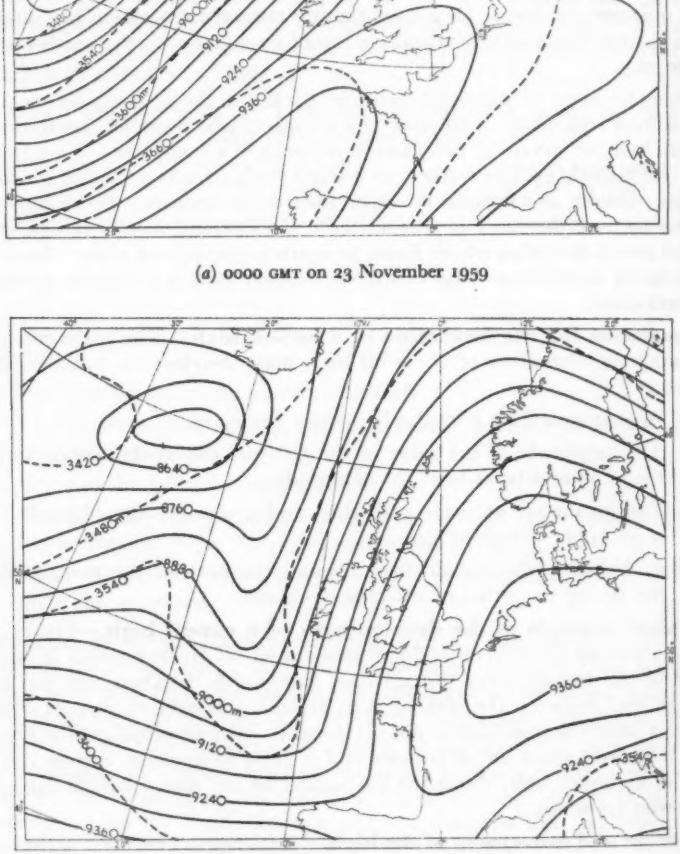
(iv) A thickness bulb should form around the peak of the thermal ridge, this giving 12–24 hours' warning of cut-off.

Typical example of the development of a cut-off high.—Figure 5(*a*), for 0000 GMT on 23 November 1959, shows a jet off Ireland which is backing ahead of the trough lying through the Azores. A thickness line just turns through 180° between the area off west Ireland and over south-west France, though a clearly defined bulb is not yet present. The amplitude of the thermal ridge is already about 22° of latitude and is likely to increase. Figure 5(*b*), the chart of 24 hours later, shows the jet backed by 20° and a cut-off high over north-west Germany.

Position and movement of the high.—A fairly good estimate of the initial latitude of a cut-off high was found to be given by the latitude of the centre of the thickness bulb 12 hours earlier. With jet directions around 140° the high was centred on the average 3° north of the thermal centre. With jet directions around 200° it was 3° south of this centre. On the other hand the difference in longitude between the two centres varied widely.



(*a*) 0000 GMT on 23 November 1959



(b) 0000 GMT on 24 November 1959

FIGURE 5—THE DEVELOPMENT OF A CUT-OFF HIGH

——— 300 mb contours - - - - 500–300 mb thickness

(Closed 3600m thickness line inadvertently omitted over the high in 5(b))

In forecasting the movement of a high from one chart to the next the best method appeared to be to make use of the rough proportionality between the advective temperature change and the change of 300 mb height. Thus a high tends to move towards regions of 500–300 mb warm advection and away from regions of cold advection. In the initial stages, as the tongue of warm air spreads round the north side of the high, the average movement of the high was 80° veered from the direction of the jet, disregarding those highs whose movement was scarcely appreciable. Apart from one high which moved in a direction 50° backed from the jet, all moved in directions between 25° and 150° veered from it, and half of these directions lay between 70° and 100° veered. With the warm air continuing to overtake the high and advance to its north-east flank the track of the high usually showed a progressive veer with time. Only two highs, both of them retrogressive, moved to the left of the initial path.

Mean speeds of the highs throughout their life were measured. Of those with jets in the south-easterly group, one-third were nearly stationary and two-thirds averaged 200–250 nautical miles per day. Highs associated with south-south-westerly jets moved rather faster, the average speed being 300 nautical miles per day, only one in five remaining nearly stationary.

Half of the 45 highs lasted no more than 3 days, but a quarter of the total persisted as closed circulations for 5 to 10 days. None of the fast-moving highs remained a closed circulation for more than 3 or 4 days but otherwise no useful indication of the life of a high came to light. There was some proportionality between persistence and the number of closed contours but on the other hand some of the longest-lived highs maintained only one or two closed contours for most of the time. A forecasting rule based on the characteristics of a single system is not of course to be expected.

Cut-off lows at the 300 mb level.—Whereas a southerly jet is accompanied by the development of an upper ridge and perhaps a cut-off high, a jet from a northerly point is accompanied by a trough which usually extends southwards and develops a cut-off low provided the jet does not propagate forward to join a pre-existing low. The jet then bifurcates, one stream—usually the weaker—re-forming the trough in higher latitudes to north of the low. Since upper lows can develop in other ways, the starting point of the investigation was not the closed circulation (as in studying upper highs) but the northerly jet, the aim being to ascertain the circumstances in which it led to the formation of a cut-off low.

All jets over Europe and the eastern North Atlantic were examined for the months October to March from October 1959 to March 1963. As with highs, attention was confined to situations in which there were enough observations to establish whether a closed upper circulation developed near the jet exit.

Direction of the jet.—It soon became evident that northerly jets backed beyond 300° scarcely ever produced lows within 24 hours, so these directions were thereafter disregarded. The number of jets remaining was 50, of which 39 became associated with cut-off lows. Of the 11 jets which did not produce lows, 9 weakened by 20 or 30 knots, and it seems that this is a reliable indicator that cut-off will not take place however favourable the situation may appear in other respects.

From the method of selection of the jets most of the lows were necessarily over southern Europe or the Mediterranean: 34 lay between 30°N and 50°N and the remaining 5 to north of this zone. Nevertheless there was no evident relationship between the distribution and the topography.

Variations in the orientation of the jets were measured at various stages. If a jet was curved the direction was taken where the jet was furthest veered, provided the wind speed there was not appreciably below the peak speed on the axis. It was found that in the period from 24 to 12 hours before the formation of a cut-off low most jets veered, a few retained the same direction and none backed. The average 12-hour veer was 17°. In the period from 36 to 24 hours before cut-off the average veer was 9°. Even from 48 to 36 hours before cut-off there was backing of only 10 per cent of the jets. Thus provided a jet does not back (or weaken) with time, a cut-off low is likely to form sooner or later. The most significant indication of cutting-off is undoubtedly the direction of the jet, and Figure 6 shows the increasing probability of this development the more northerly the jet becomes, disregarding other factors.

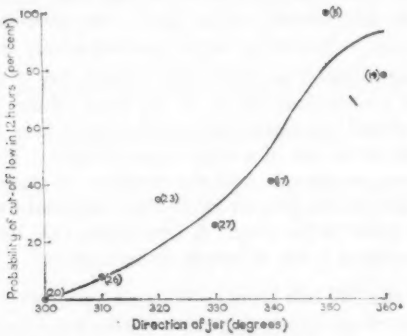


FIGURE 6—PROBABILITY OF CUT-OFF LOW IN RELATION TO JET DIRECTION
Number of occasions in brackets.

Amplitude of the thermal trough.—The veering of a jet is clearly accompanied on most occasions by increasing amplitude of the trough in the 300 mb contour lying along the jet axis, this amplitude being measured between the upwind ridge and the downwind trough. A linear relationship was found between the amplitude of the trough and the direction of the jet but, as was found with highs, amplitude gave only a rough indication of the imminence of cut-off. A low was cut-off within 12 hours only once when the amplitude was 10° of latitude or less.

Shape of the thickness lines.—An additional criterion was again provided by the shape of the 500–300 mb thickness lines. Whether the jet had propagated in such a way as to form a thickness bulb (as defined earlier for a ridge) at the base of the trough was found to be significant with jets between 320° and 340°.

Conditions for the formation of a cut-off low.—The complete rules suggested for forecasting a cut-off low are as follows:

(i) Cut-off is very unlikely within 12 hours if the amplitude of the trough

in the 300 mb contour through the jet does not exceed 10° latitude.

(ii) Cut-off is very unlikely if the jet weakens by 20–30 knots.

(iii) A jet direction not further back than 310° is necessary for cut-off within 12 hours.

(iv) With a jet direction 300–310° there is
  (*a*) 75 per cent probability of no low in 24 hours or less
  (*b*) 5 per cent probability of a low in 12 hours.

(v) With a jet direction 320°–340° and no thickness bulb there is
  (*a*) 60 per cent probability of no low in 24 hours or less
  (*b*) 10 per cent probability of a low in 12 hours.

(vi) With a jet direction 320°–340° and a thickness bulb there is
  (*a*) 85 per cent probability of a low in 24 hours or sooner
  (*b*) 55 per cent probability of a low in 12 hours.

(vii) With a jet direction 350° or further veered, regardless of the existence of a thickness bulb, there is 80 per cent probability of a low in 12 hours.

Position and movement of the low.—Whereas the latitude of cut-off highs was fairly well related to the thickness bulb, the latitude of cut-off lows varied widely from it, and the narrower the 300 mb trough the more uncertain seemed the latitude of cut-off. On the other hand the longitude of the low was closely linked to that of the trough and averaged 4° longitude to east of the centre of the thickness bulb on the chart 12 hours before cut-off.

The directions of movement of the cut-off lows varied considerably from one system to another, depending to some extent on whether there was an associated surface depression and how strong it was. When there was already a surface system moving towards an easterly point, the upper low tended to move east or north of east. Nevertheless half the total number of 300 mb lows moved south-east into the sector 120°–140° during the first 24 hours. Meanwhile the base of the trough re-formed to north of the low and usually moved north of east, subsequently turning to east or south-east. 85 per cent of the lows moved a distance between 250 and 500 nautical miles in the first 24 hours, the average of them all being 350 nautical miles.

Half the lows persisted as closed circulations for no more than 2 days and only one-quarter of the total existed for more than 3 days. Three-quarters of the lows showed a net filling during the first 24 hours of life but there was no indication that the change in contour height over the centre was related to the life of the closed circulation.

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ASPECTS OF THE SYNOPTIC CLIMATOLOGY OF CENTRAL SOUTH ENGLAND

551.589.1

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Introduction.—Since the investigations of Abercromby,[1] much attention has been devoted to the description of pressure-map patterns over Europe[2] and over the British Isles.[3,4] Little attempt has been made, however, to determine in quantitative terms the resultant weather and synoptic climatology of characteristic pressure-patterns, despite the early study of local weather in selected areas of Britain in relation to 'weather types' by Sir Napier Shaw[5] and similar investigations for Cranwell.[6]

The present study attempts to provide more precise information of temperatures and rainfall in relation to pressure patterns for January and July, 1921–50, using the daily synoptic classification of H. H. Lamb[4] for the area of the British Isles. Daily averages of maximum and minimum temperature have been calculated for each type of pressure situation at ten stations in central south England, and averages of precipitation at twelve stations (Figure

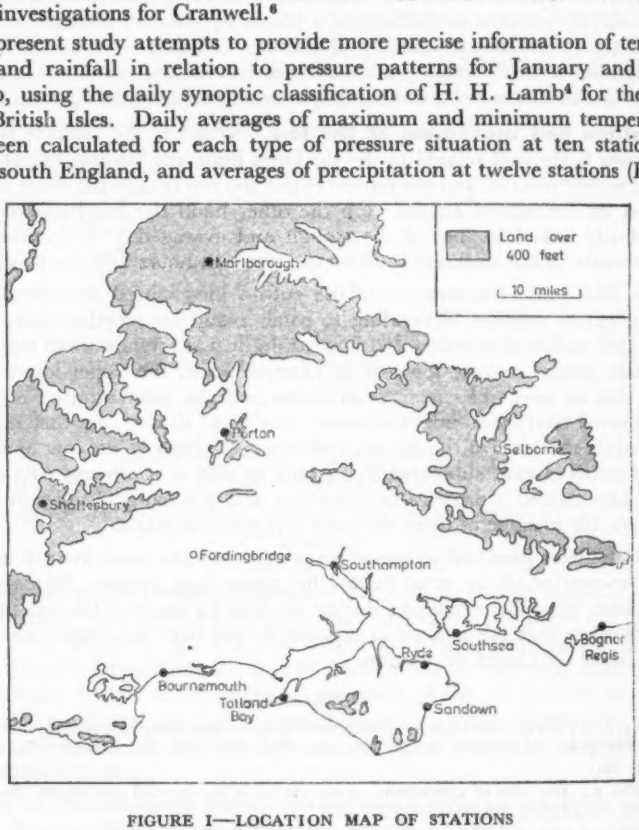

FIGURE 1—LOCATION MAP OF STATIONS
• stations recording temperature and rainfall data
o stations recording rainfall data only.

1). In addition to these averages, standard deviations were also determined in each case, using the expression

$$\sqrt{\left\{ (n\Sigma x^2 - (\Sigma x)^2) \Big/ n(n-1) \right\}}$$

where Σ indicates summation of data, n is the number of terms and x data element. The work was performed on the *Pegasus* computer at the University of Southampton

Climatic conditions in January.—The results are set out in Table I, though synoptic types which accounted individually for fewer than 2½ per cent of the 930 days are omitted. Comparisons between stations are facilitated by the figures of departures of the calculated average temperatures for each type from the mean January values for 1921–50.[7] Complete descriptions of the type categories may be found in the paper by Lamb[4] and are not repeated here.

The *Westerly type*, which is the most common weather-map pattern (40 per cent frequency in January), brings relatively mild, changeable weather as depressions pass eastwards across the country. Moderate rainfall occurs with this type and the *Cyclonic westerly sub-type* (3 per cent frequency); 24-hour precipitation averages 2.5 to 3.4 mm over most of the region, although the higher figure at Selborne reflects orographic intensification over the western edge of the South Downs. Average daily maximum and minimum temperatures with Westerly flow are 1 to 2°C above mean January values at all stations. The high minima indicate a tendency for persistent cloud cover at night.

The *Cyclonic type* (12 per cent frequency) refers either to periods of very frequent depression passages across Britain or to a slow-moving low-pressure area lying over the whole country. Average minimum temperatures for Cyclonic type are about a degree above the mean minimum for January as a result of large cloud amounts, but average maxima are near the mean values (Table I). However, these averages may conceal high variability, arising from the changeable wind directions within depressions. For example, the standard deviation of the average maximum with Cyclonic type is between 2.5 and 3.3°C at ten stations, compared with 1.7 to 2.2°C for Westerly types, Cyclonic type is another major contributor to precipitation totals in January. since average daily falls are of the order of 4 mm. Similar high daily averages occur on days which are *Unclassifiable* (Table I), because these cases mainly represent complex synoptic situations with a depression affecting only part of the country.

North-westerly situations (4 per cent frequency) bring cold, generally unstable air across Britain when a northward extension of the Azores anticylcone causes depressions to approach from the north-west. Daily precipitation amounts average only 0.5 to 1.5 mm, although over high ground precipitation may take the form of snow showers. Average daily maxima and minima with North-westerly flow are close to the January averages at each station, with many occurrences of night air frost over high ground (Table I). Similar, but more extreme, conditions pertain to *Northerly* airflow when high pressure over the North Atlantic extends in a south to north wedge between 40° and 65°N, (3 per cent frequency in January). Average maxima with Northerly flow are 4 to 5°C at lowland stations and about 3°C on higher ground, whilst minima are −1 to 1°C and −2°C respectively. Despite the low day temperatures, little cloud cover is usually associated with Northerly flow and the winter sunshine provides some compensation for the cold air. Northerly flow is essentially unstable, but showers (not infrequently of snow) are only light over southern England due to the long passage of the air over land.

TABLE I—AVERAGES OF DAILY PRECIPITATION AND TEMPERATURES FOR TYPES OF AIRFLOW IN JANUARY (1921–50)

Type†		*NW*	*N*	*E*	*S*	*ACW*	*W*	*CW*	*C*	*AC*	*U*
Number of cases		35	32	49	105	23	372	28	110	96	43
Station	Height in feet	Precipitation *millimetres*									
Bognor Regis	24	0.8	0.8	2.7	2.8	0.3	2.9	2.6	4.0	0.6	4.0
Bournemouth (1)	139	1.3	0.7	2.1	4.2	0.7	2.8	2.7	4.1	0.7	4.5
Sandown	13	1.5	0.9	2.5	3.8	0.3	3.3	2.7	3.8	0.6	3.6
Ryde	13	1.0	0.7	2.7	3.7	0.6	3.3	2.9	4.0	0.5	3.6
Totland Bay (2)	140	1.1	0.5	2.5	4.1	0.8	3.1	2.6	4.3	0.7	3.8
Southsea (1)	7	1.1	0.6	2.4	3.4	0.3	2.9	2.5	3.9	0.6	3.7
Fordingbridge (3)	140	1.5	0.7	2.9	2.8	1.1	2.8	4.7	6.7	0.7	6.5
Southampton	65	1.0	0.6	2.4	3.8	0.5	3.3	3.4	4.2	0.6	3.9
Selborne	400	0.9	0.9	2.8	4.1	0.2	4.3	4.8	5.4	0.6	5.2
Porton	363	0.5	0.6	2.1	3.4	0.3	2.8	2.3	3.7	0.5	4.1
Shaftesbury	680	0.9	0.9	1.8	3.6	0.8	2.9	2.8	3.6	0.7	3.6
Marlborough	424	1.1	1.1	1.9	3.1	0.5	3.5	3.8	4.2	0.6	3.6
		Mean daily maximum temperature and departure from January average *degrees Celsius*									
Bognor Regis		7.6	4.7	4.1	7.3	7.7	9.1	9.4	7.8	4.7	5.9
		*0.2	−2.7	−3.3	−0.1	0.3	1.7	2.0	0.4	−2.7	−1.5*
Bournemouth		7.9	4.9	3.9	7.7	7.8	9.6	10.0	8.1	4.7	6.1
		*0.1	−2.9	−3.9	−0.1	0.0	1.8	2.2	0.3	−3.1	−1.7*
Sandown		8.1	4.7	4.4	8.0	7.9	9.8	10.2	8.5	5.2	6.6
		*0.0	−3.4	−3.7	−0.1	−0.2	1.7	2.1	0.4	−2.9	−1.5*
Ryde		7.8	4.7	4.2	7.9	7.3	9.7	10.2	8.3	4.7	6.1
		*−0.1	−3.2	−3.7	0.0	−0.6	1.8	2.3	0.4	−3.2	−1.8*
Totland Bay (2)		7.6	4.4	3.7	7.9	7.6	9.3	9.9	7.9	4.3	6.3
		*−0.1	−3.3	−4.0	0.2	−0.1	1.6	2.2	0.2	−3.4	−1.4
Southsea		7.9	4.7	4.3	7.7	7.5	9.4	10.0	8.3	5.1	6.1
		*0.0	−3.2	−3.6	−0.2	−0.4	1.5	2.1	0.4	−2.8	−1.8*
Southampton (4)		8.0	5.1	3.7	7.4	7.4	9.5	10.2	8.2	4.8	5.9
		*0.3	−2.6	−4.0	−0.3	−0.3	1.8	2.5	0.5	−2.9	−1.8*
Porton		6.8	3.5	2.6	6.7	6.8	8.9	9.3	7.1	3.8	4.8
		*−0.1	−3.4	−4.3	−0.2	−0.1	2.0	2.4	0.2	−3.1	−2.1
Shaftesbury		6.4	3.3	2.6	6.9	6.4	8.3	8.6	6.7	3.3	5.0
		*−0.2	−3.3	−4.0	0.3	−0.2	1.7	2.0	0.1	−3.3	−1.6*
Marlborough		7.2	3.3	2.5	6.5	6.9	8.8	9.2	6.9	3.4	4.6
		*0.4	−3.5	−4.3	−0.3	0.1	2.0	2.4	0.1	−3.4	−2.2*
		Mean daily minimum temperature and departure from January average *degrees Celsius*									
Bognor Regis		2.2	−0.3	−0.1	2.4	1.8	3.9	4.6	3.6	−0.2	1.3
		*−0.4	−2.9	−2.7	−0.2	−0.8	1.3	2.0	1.0	−2.8	−1.3*
Bournemouth		2.6	−0.4	−0.6	2.0	1.3	3.8	4.1	3.3	−1.2	1.3
		*0.4	−2.6	−2.8	−0.2	−0.9	1.6	1.9	1.1	−3.4	−0.9*
Sandown		3.1	0.2	0.6	3.3	2.3	4.3	4.7	3.8	0.3	2.1
		*0.0	−2.9	−2.5	0.2	−0.8	1.2	1.6	0.7	−2.8	−1.0*
Ryde		3.2	0.4	0.6	2.7	2.2	4.4	4.9	3.8	0.5	1.9
		*0.2	−2.6	−2.4	−0.3	−0.8	1.4	1.9	0.8	−2.5	−1.1*
Totland Bay (2)		3.1	0.4	0.0	2.7	2.0	4.4	5.3	3.8	−0.4	1.9
		*0.0	−2.7	−3.1	−0.4	−1.1	1.3	2.2	0.7	−3.5	−1.2*
Southsea		3.2	0.6	0.2	2.8	2.3	4.2	4.8	3.9	0.0	1.7
		*0.2	−2.4	−2.8	−0.2	−0.7	1.2	1.8	0.9	−3.0	−1.3*
Southampton (4)		2.1	−0.3	−1.0	2.1	0.5	3.4	3.8	3.0	−1.1	0.9
		*0.1	−2.3	−3.0	0.1	−1.5	1.4	1.8	1.0	−3.1	−1.1*
Porton		0.6	−2.3	−1.5	−0.1	−0.7	1.7	1.7	1.4	−2.7	−0.7
		*0.3	−2.6	−1.8	−0.4	−1.0	1.4	1.4	1.1	−3.0	−1.0*
Shaftesbury		0.8	−1.6	−2.0	1.2	1.3	2.8	2.6	1.6	−1.9	−0.3
		*−0.4	−2.8	−3.2	0.0	0.1	1.6	1.4	0.4	−3.1	−1.5*
Marlborough		0.6	−2.3	−1.7	−0.3	−0.9	1.8	2.2	1.3	−2.8	−0.8
		*0.2	−2.7	−2.1	−0.7	−1.3	1.4	1.8	0.9	−3.2	−1.2*

†*NW*=Northwesterly; *N*=Northerly; *E*=Easterly; *S*=Southerly; *ACW*=Anticyclonic westerly; *W*=Westerly; *CW*=Cyclonic westerly; *C*=Cyclonic; *AC*=Anticyclonic; *U*=Unclassifiable.
*Starred lines give the departure from average in both temperature tables. Notes: (1)1926–50 only; (2)1921–47 only; (3)Dockens 1922, 1927–47, 1949 and 1950; Cuckoo Hill (150 feet) 1921 and 1923–26; Furze Hill (150 feet) 1948; (4)No data for January 1941.

Easterly airflow has given rise to some memorable winters, but it is generally rather infrequent in January (8 per cent occurrence, including the Cyclonic easterly and Anticyclonic sub-types). Easterly spells usually develop with the establishment of a blocking anticyclone over Scandinavia, which may subsequently extend westwards. This situation can become persistent, as in the severe winter of 1947, and the conditions of January 1963 provide a further example. At Southampton, the temperatures in January 1963 fell considerably below the calculated average maximum of 3.7°C and the average minimum of −1.0°C for Easterly type (Table I), as Figure 2 shows. The hybrid

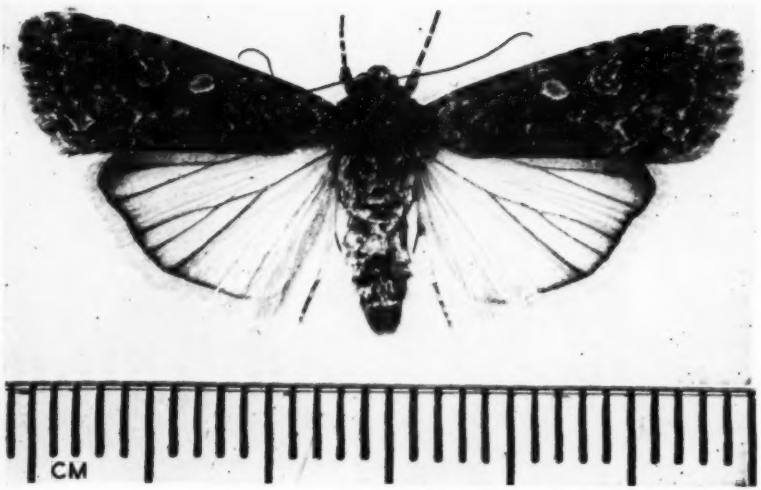

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PLATE I—SMALL MOTTLED WILLOW MOTH (LAPHYGMA EXIGUA)

See page 309

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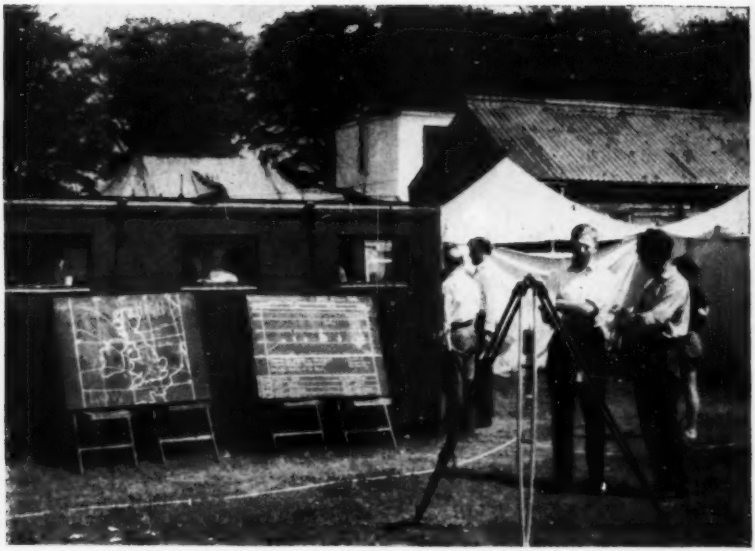
PLATE II—LIGHT TRAP USED BY ENTOMOLOGISTS

See page 309



Photograph by T. A. M. Bradbury

PLATE III—METEOROLOGICAL OFFICE UNIT AT THE NATIONAL GLIDING CHAMPIONSHIPS AT LASHAM FROM 25 MAY TO 3 JUNE 1963

See page 317

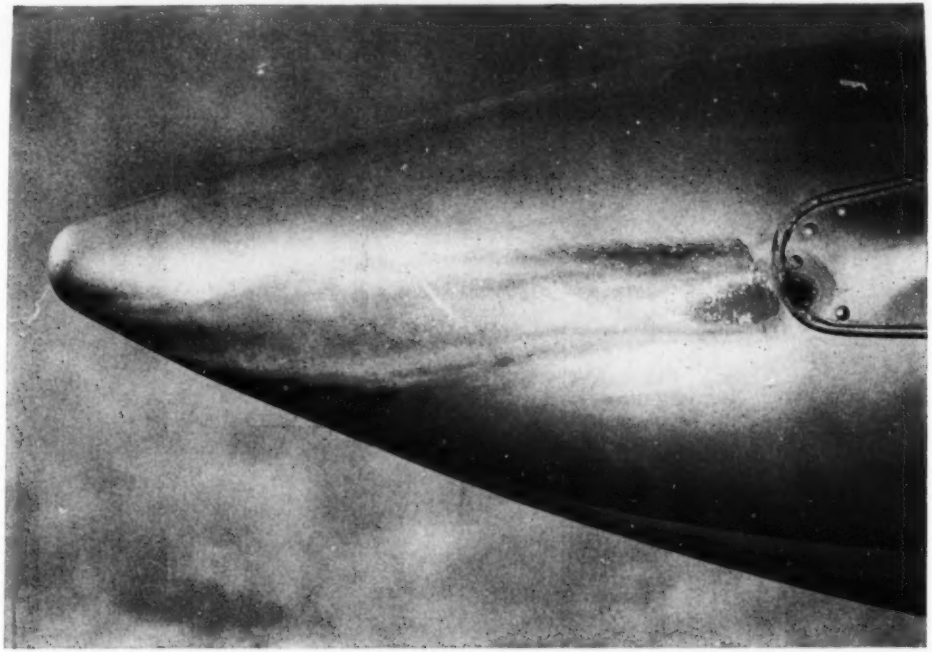


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PLATE IV—DAMAGE CAUSED TO A JET PROVOST WING-TIP TANK BY LIGHTNING ON 3 APRIL 1963

The aircraft, based at RAF Cottesmore, was flying at 7000 feet in a cumulus-type cloud

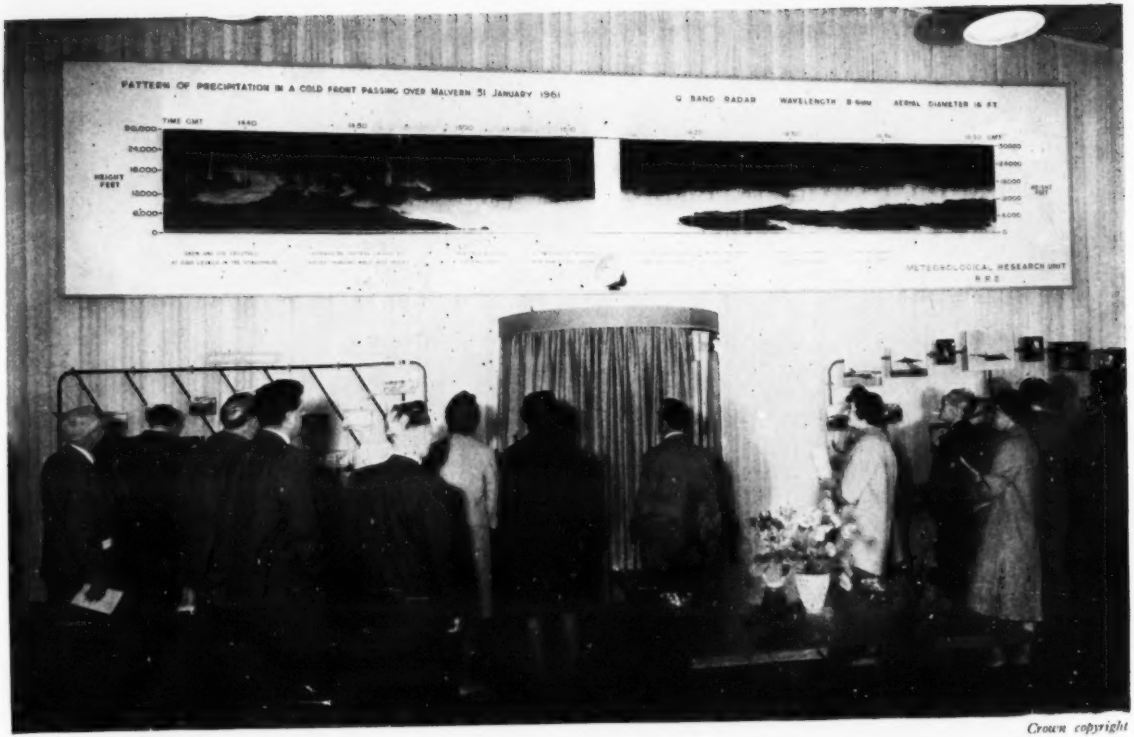

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PLATE V—DISPLAY PANEL IN THE INFORMATION CENTRE AT THE ROYAL RADAR ESTABLISHMENT, MALVERN

On the occasion of the Open Days from 21 to 25 May 1963. (*see* page 317).

PLATE V—DISPLAY PANEL IN THE INFORMATION CENTRE AT THE ESTABLISHMENT, MALVERN
On the occasion of the Open Days from 21 to 25 May 1963. (see page 317).

North-easterly and South-easterly types of January and February 1963 were not recorded during January 1921–50. Average daily precipitation over the area is about 2 mm with Easterly type, although on occasions moderate falls of snow may occur.

Cold weather in January occurs most frequently with the high pressure or *Anticyclonic type* (10 per cent frequency). Average maxima and minima for these cases are 3°C below the respective monthly averages, and night frosts are common, even at exposed coastal stations. The low averages of daily maxima reflect the development of frequent winter anticyclones in cold polar continental air from central or northern Europe, or in polar maritime air from the area between Greenland and the Faeroes. Precipitation falls occasionally on days which are classified as mainly Anticyclonic, but amounts are small (Table I).

Southerly flow (11 per cent frequency) is usually associated with anticyclonic blocking over Britain or the North Sea, or over central and northern Europe. The weather associated with this type cannot be readily specified, since a spell of Southerly flow may alternate either with Westerly or Easterly flow, giving rise to rather different conditions over southern England. Figure 2 provides an illustration of the latter case during February 1963. Thus,

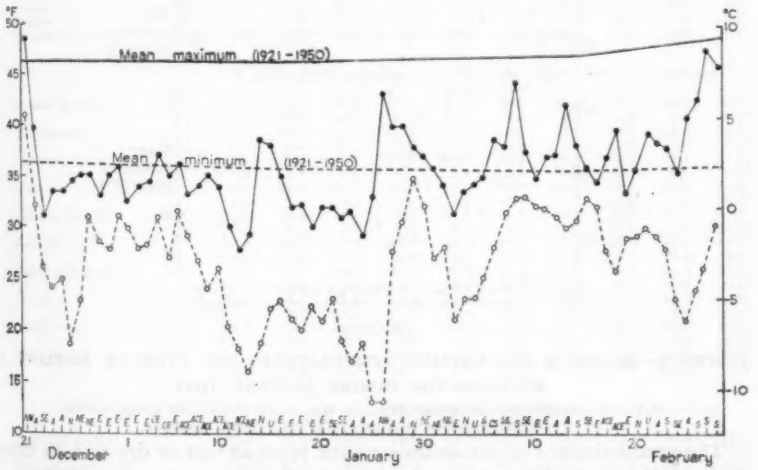

FIGURE 2—MAXIMUM AND MINIMUM TEMPERATURES AND TYPES OF AIRFLOW AT SOUTHAMPTON DURING THE WINTER 1962–63

· ——— · maximum temperatures o – – – o minimum temperatures.

N=Northerly; *E*=Easterly; *S*=Southerly; *W*=Westerly; *NW*=North-westerly; *NE*=North-easterly; *SE*=South-easterly; *C*=Cyclonic; *A*=Anticyclonic; *CW*=Cyclonic westerly; *ACW*=Anticyclonic westerly; *CE*=Cyclonic easterly; *ACE*=Anticyclonic easterly; *CS*=Cyclonic southerly.

although the calculated temperatures are close to the averages for January (Table I), the values conceal considerable variability. Standard deviations of average maxima with Southerly type are 2.3 to 3.4°C. Average daily precipitation (generally rain) is 3 to 4 mm with Southerly flow.

While the averages of daily precipitation and daily maximum and minimum temperatures provide in general a useful indication of the climatic character-

istics for particular types of synoptic pressure patterns, it must be recognized that non-characteristic conditions may be associated with any synoptic type over at least part of Britain. For example, January 1942 was much colder than average in central south England, despite the occurrence of 10 days of Westerly type during the month. The low temperatures were not related to any single flow-type and in fact were below average even on days of Westerly flow. Nevertheless, the very warm Januarys of 1921, 1932 and 1944 can be ascribed to an incidence of 20 or more days of Westerly type in each month. Temperatures at Southampton during January 1921 (Figure 3) were well above the monthly mean values on all except a few days. The very cold weather in central south England during the Januarys of 1929, 1940, 1941 and 1945 was associated with mixed spells of Northerly, Easterly, Anticyclonic and Southerly types, rather than with a single type.

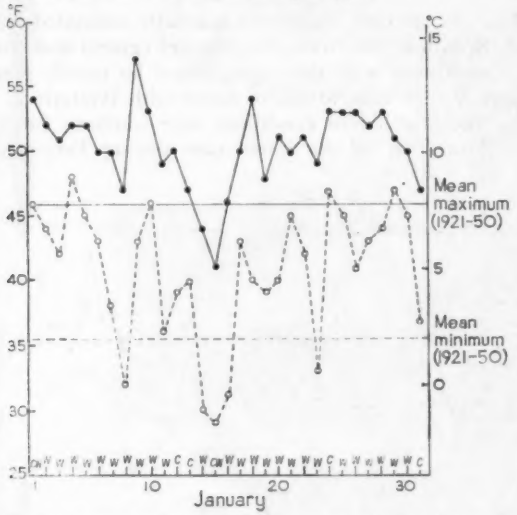

FIGURE 3—MAXIMUM AND MINIMUM TEMPERATURES AND TYPES OF AIRFLOW AT SOUTHAMPTON DURING JANUARY 1921

·————· maximum temperatures o – – – o minimum temperatures.
C=Cyclonic; *W*=Westerly; *CW*=Cyclonic westerly.

The predominance of particular synoptic types in wet or dry months shows similar diversity. The area experienced above average precipitation in January 1936, 1939 and 1943, and each of these months had 8 or more days of Cyclonic type, though with spells of Westerly flow, and the Unclassifiable and Southerly types were also prominent. The extremely wet January of 1937, with 172 mm recorded at Southampton, had 17 days of Westerly type and 7 days of Southerly type. In contrast, Southampton received little precipitation in January 1949 and 1950, despite a high proportion of days with Westerly and Southerly flow, while Anticyclonic conditions were primarily responsible for the low precipitation in the area during January 1934.

Climatic conditions in July.—*Westerly type* (31 per cent frequency) is accompanied by below average maximum temperatures in July mainly as a result of its maritime origin, although cloud cover helps to keep the minima

close to the mean monthly values (Table II). Rainfall may be widespread, but daily amounts average only a little over 1 mm. The *Cyclonic westerly sub-type* brings somewhat lower temperatures by day and precipitation averages of 1.5 to 3 mm. Although these values are less than in January, the amounts still provide an important contribution to summer rainfall totals. *Cyclonic type* situations, which are more frequent in July (19 per cent) than January, give similar maxima to those with the Cyclonic westerly sub-type (18 to 20°C). Average rainfall, some of which occurs with thunderstorms, is 3 to 4 mm at lowland stations and approximately 5 mm at Selborne, Shaftesbury and Marlborough, where orographic influence increases the amounts.

TABLE II—AVERAGES OF DAILY PRECIPITATION AND TEMPERATURES FOR TYPES OF AIRFLOW IN JULY (1921–50)

Types†		*NW*	*N*	*E*	*S*	*ACW*	*W*	*CW*	*C*	*AC*	*U*
Number of cases		52	39	26	43	37	293	46	176	137	48
Station	Height in feet					Precipitation *millimetres*					
Bognor Regis (1)	24	0.8	0.5	4.3	2.9	0.3	1.1	1.7	3.8	0.6	1.6
Bournemouth (2)	139	0.7	1.7	5.0	2.6	0.6	1.2	1.5	3.1	0.6	2.0
Sandown	13	1.1	0.6	5.2	2.8	0.5	1.3	1.9	3.8	0.6	1.7
Ryde	13	0.8	0.3	3.9	2.4	0.3	1.1	1.7	3.7	0.5	1.8
Totland Bay (3)	140	0.7	1.1	4.7	1.4	0.3	1.3	1.7	3.6	0.6	2.1
Southsea (2)	7	0.7	0.6	4.7	2.9	0.3	1.1	1.6	3.1	0.6	1.7
Fordingbridge	140	1.4	0.9	2.9	2.2	0.6	1.3	1.9	3.9	0.5	1.9
Southampton	65	1.1	0.7	2.8	2.7	0.9	1.1	2.0	4.4	0.6	1.1
Selborne	400	1.5	1.0	4.4	4.5	1.0	1.4	2.6	5.4	0.7	1.7
Porton	363	0.9	0.6	5.4	2.1	0.4	1.3	2.0	3.7	0.5	1.7
Shaftesbury	680	0.7	0.8	2.3	1.7	0.4	1.4	3.0	4.7	0.4	2.1
Marlborough	424	0.9	0.9	4.0	2.1	0.4	1.6	2.5	4.5	0.9	2.1
		Mean daily maximum temperature and departure from July average *degrees Celsius*									
Bognor Regis (1)		19.3	18.1	20.6	20.1	21.6	19.7	18.4	18.7	21.6	20.6
		*−0.6	−1.8	0.7	0.2	1.7	−0.2	−1.5	−1.2	1.7	0.7*
Bournemouth		20.3	19.3	21.5	21.9	23.7	21.1	19.6	19.7	24.0	21.8
		*−1.1	−2.1	0.1	0.5	2.3	−0.3	−1.8	−1.7	2.6	0.4*
Sandown		19.9	18.9	21.0	20.7	22.6	20.4	19.3	19.3	22.1	20.7
		*−0.6	−1.6	0.5	0.2	2.1	−0.1	−0.8	−0.8	−1.6	0.2*
Ryde		20.1	19.1	21.2	21.8	23.4	20.9	19.7	19.7	22.9	21.3
		*−0.9	−1.9	0.2	0.8	2.4	−0.1	−1.3	−1.3	1.9	0.3*
Totland Bay (3)		19.3	18.5	20.8	21.1	21.8	19.2	18.1	18.6	22.1	20.1
		*−0.5	−1.3	1.0	1.3	2.0	−0.6	−1.7	−1.2	2.3	0.3*
Southsea (4)		20.1	18.8	22.2	22.2	23.3	21.1	20.0	20.0	23.5	21.7
		*−1.2	−2.5	0.9	0.9	2.0	−0.2	−1.3	−1.3	2.2	0.4*
Southampton (5)		20.2	19.2	22.6	22.9	23.9	21.2	19.6	19.8	24.4	21.6
		*−1.3	−2.3	1.1	1.4	2.4	−0.3	−1.9	−1.7	2.9	0.1*
Porton		19.4	18.6	21.6	22.9	23.8	21.1	19.6	19.7	24.3	21.8
		*−1.9	−2.7	0.3	1.6	2.5	−0.2	−1.7	−1.6	3.0	0.5*
Shaftesbury		18.4	17.6	20.1	21.4	22.7	19.6	17.8	18.3	23.2	20.3
		*−1.5	−2.3	0.2	1.5	2.8	−0.3	−2.1	−1.6	3.3	0.4*
Marlborough		19.4	18.3	21.7	22.9	23.8	20.7	19.4	19.4	24.7	21.6
		*−1.8	−2.9	0.5	1.7	2.6	−0.5	−1.8	−1.8	3.5	0.4*
		Mean daily minimum temperature and departure from July average *degrees Celsius*									
Bognor Regis (1)		12.0	11.3	14.5	14.7	12.3	13.3	13.2	14.1	13.4	13.5
		*−1.4	−2.1	1.1	1.3	−1.1	−0.1	−0.2	0.7	0.0	0.1*
Bournemouth		11.6	10.8	13.6	13.6	11.4	12.7	12.6	13.2	12.4	12.7
		*−1.1	−1.9	0.9	0.9	−1.3	0.0	−0.1	0.5	−0.3	0.0*
Sandown		12.3	11.8	14.6	14.8	12.4	13.3	13.1	13.9	13.7	13.6
		*−1.1	−1.6	1.2	1.4	−1.0	−0.1	−0.3	0.5	0.3	0.2*
Ryde		12.9	12.1	14.7	14.4	13.2	13.5	13.1	13.7	14.0	13.7
		*−0.7	−1.5	1.1	0.8	−0.4	−0.1	−0.5	0.1	0.4	0.1*
Totland Bay (3)		12.4	12.0	13.7	13.9	11.7	13.2	13.1	13.3	12.7	13.3
		*−0.8	−1.2	0.5	0.7	−1.5	0.0	−0.1	0.1	−0.5	0.1*
Southsea (4)		12.7	11.9	14.8	15.0	12.8	13.9	13.4	14.2	14.1	14.1
		*−1.2	−2.0	0.9	1.1	−1.1	0.0	−0.5	0.3	0.2	0.2*
Southampton		11.4	10.7	14.1	13.9	11.6	12.7	12.3	13.3	12.8	12.7
		*−1.3	−2.0	1.4	1.2	−1.1	0.0	−0.4	0.6	0.1	0.0*
Porton		9.5	8.9	12.6	12.1	9.0	10.5	10.6	11.5	10.5	10.9
		*−1.2	−1.8	1.9	1.4	−1.7	−0.2	−0.1	0.8	−0.2	0.2*
Shaftesbury		10.3	9.6	12.1	12.2	11.2	11.3	10.8	11.5	12.1	11.2
		*−1.1	−1.8	0.7	0.8	−0.2	−0.1	−0.6	0.1	0.7	−0.2*
Marlborough		9.2	8.8	11.9	11.2	8.3	10.7	10.4	11.5	9.5	10.3
		*−1.2	−1.6	1.5	0.8	−2.1	0.3	0.0	1.1	−0.9	−0.1*

†See Table I for identification of types. *Starred lines give the departure from average in both temperature tables. Notes: (1) No data for July 1923; (2) 1926–50 only; (3) 1921–47 only; (4) No data for July 1929; (5) No data for 1–23 July 1941.

North-westerly (6 per cent) and *Northerly* (4 per cent) situations are slightly more frequent in July than January. Each type of airflow brings relatively cool, showery weather, although in southern England falls are generally slight (Table II). Northerly type gives, on average, the lowest maxima and minima, which are 2 to 3°C and 2°C respectively below the mean values for July.

Easterly type is infrequent in July (3 per cent occurrence) largely as a result of the low frequency of blocking anticyclones over Europe.[8] Temperatures, especially minima, are above average when Easterly flow from the continent does occur in July. Daily rain amounts with Easterly flow in July average 3 to 5 mm, except further west at Shaftesbury; the rain tends to occur as thundery showers.

Southerly flow is also less frequent in July (5 per cent of days). Temperature conditions are almost identical with those for Easterly type, though rainfall is less. Average daily falls range from 1.5 to 3 mm, except where the orographic influence of the South Downs increases the figure to 4.5 mm at Selborne (Table II).

The highest average maxima in July occur with *Anticyclonic type* situations (15 per cent frequency) at all stations (except Ryde and Sandown); in some cases the average maxima are 3°C above the mean July maximum. Actual values are several degrees lower at coastal stations than inland, because of the development of sea breezes on many occasions,[9,10] Average minima with Anticyclonic type in July are close to the monthly mean minimum (Table II).

The *Unclassifiable* category accounts for 5 per cent of days in July, as in January, although a much smaller proportion of the month's precipitation falls on these days. Average temperatures are also closer to the monthly mean values (Table II).

The typical features of the synoptic patterns in July are not necessarily found every year (see also the discussion of January conditions). In July 1921 and July 1934 high average maximum temperatures and dry conditions were experienced at Southampton, and two-thirds of each month was dominated by Westerly and Anticyclonic types. Similarly, there were 18 and 20 days of Westerly flow during July 1923 and July 1933 respectively, occurring in long spells, and both were dry months with temperatures well above average at Southampton. The July minima in these latter cases were the two highest at Southampton during the period 1921–50. In July 1922, on the other hand, there were 15 days of Westerly type, 4 of the Cyclonic westerly sub-type and 7 days of Cyclonic type, but at Southampton the average daily maximum and minimum temperatures were well below average, and the rainfall total of 109 mm was the third highest for Southampton during 1921–50. The Westerly days in this month, however, did not constitute a long spell and the occurrence of a similar sequence in July 1936, again a very wet, cool month at Southampton, emphasizes the need to take into account not simply the total frequency of a type, but also the duration of particular spells and their relation to other synoptic types.

Significance tests.—Inspection of Tables I and II suggests that there may be no significant difference between the calculated averages for some of the sub-types, and even for major categories. In order to check this possibility,

certain of the calculated type-averages have been tested in pairs by Student's *t*-test for temperatures at Southampton. The results for Southampton (Table III) show that, *of the pairs tested*, only Westerly and Anticyclonic westerly types are significantly different with respect to averages of maximum and minimum temperature in both months, and several pairs of types do not differ significantly for average maxima or minima. However, a complete analysis of the variance within and between the type categories, as suggested by Godske,[11] is desirable to clarify the present rather tentative results.

TABLE III—SIGNIFICANCE LEVELS (PER CENT) FOR *t*-TESTS OF THE MEAN DAILY VALUES FOR TYPE CATEGORIES FOR SOUTHAMPTON

Types	Data	Maximum temperature	Minimum temperature
NW – N	January	0.1	0.5
	July	2.0	n.s.
N – E	January	n.s.	n.s.
	July	0.1	0.1
W – ACW	January	0.1	0.1
	July	0.1	0.5
W – CW	January	n.s.	n.s.
	July	0.1	n.s.
CW – C	January	0.1	n.s.
	July	n.s.	0.2
ACW – A	January	0.1	5.0
	July	n.s.	1.0
NW – S	January	n.s.	n.s.
	July	0.1	0.1
E – S	January	0.1	0.1
	July	n.s.	n.s.

n.s. = not significant, 5 per cent probability level adopted here.

Daily rainfall values possess a J-shaped distribution with the mode at zero and consequently the arithmetic mean is not a satisfactory statistic. The calculation of frequency distributions for rainfall amounts will be undertaken with a further computer programme in future. Nevertheless, the general comparability of averages for each airflow-type between the stations and the magnitude of the differences between the averages for the major type categories are sufficient to indicate the possible value of this approach.

More detailed information about rainfall amounts has been calculated for Southampton (Tables IV and V). The median and quartile values show that particularly marked differences exist between Northerly and Easterly

TABLE IV—MEDIANS AND QUARTILES OF DAILY PRECIPITATION (mm) AT SOUTHAMPTON FOR TYPE CATEGORIES (1921–50)

	NW	*N*	*E*	*S*	*ACW*	*W*	*CW*	*C*	*AC*
(*a*) January									
Upper quartile	0.6	0.5	2.3	6.8	0.3	2.2	3.7	6.4	0.0
Median	0.0	0.0	0.0	0.6	0.0	0.3	1.5	2.9	0.0
Lower quartile	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	0.0
(*b*) July									
Upper quartile	1.2	0.7	3.0	2.6	0.0	0.6	2.6	4.8	0.0
Median	0.0	0.0	1.2	0.3	0.0	0.0	0.3	1.5	0.0
Lower quartile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE V—PERCENTAGE OF DAYS WITHOUT MEASURABLE RAINFALL AT SOUTHAMPTON FOR TYPE CATEGORIES (1921–1950)

	NW	*N*	*E*	*S*	*ACW*	*W*	*CW*	*C*	*AC*
January	57	72	53	38	61	47	18	19	82
July	58	67	38	46	81	63	41	30	88

types in July and between Westerly and Cyclonic westerly types, Westerly and Anticyclonic westerly types and North-westerly and Southerly types in January. The supplementary data of Table V also demonstrate that the number of rain days differs considerably for the Westerly sub-types and the Cyclonic type according to season.

It is intended to develop the investigations along the lines indicated above, as well as for other climatological parameters and other parts of Britain, with an extended computer programme. It is hoped that the availability of such data will help to complement the broader scale of research into climatic analogues carried out by the Meteorological Office and provide material of some assistance for extended-range forecasting.

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551.515.8:551.552:595.78

SMALL MOTTLED WILLOW MOTH IN SOUTHERN ENGLAND, 1962

By G. W. HURST

Introduction.—The agricultural branch of the Meteorological Office exists primarily to assist the agricultural community with problems in which meteorological factors come into play. Such problems are diversified, ranging from considerations of shelter in open country, some aspects of irrigation, ventilation and animal comfort, plant and animal diseases to pest control, etc. In these and many other directions positive help has been provided, but by their very nature many of the questions asked do not permit of very precise answers. From time to time, however, fairly exact questions are asked, and sometimes exact answers can be given; such a case was the arrival of the small mottled willow moth (*Laphygma exigua*) in 1962.

Many species of insect are not indigenous to this country but arrive here as immigrants in spring, or perhaps at other times when winds are favourable. The diamond-back moth in east Britain was a case where moths were traced back to west Russia (R. A. French and J. H. White),[1] and similar work in tracing spore back was done on black stem rust of wheat spore (W. H. Hogg).[2] Some insects, especially the more remotely based ones, are very variable in the regularity of their presence, and the small mottled willow moth (seen in Plate I) is a case in point. It has been thought worth-while to discuss the occasion of their arrival in May 1962 as it is very well documented, and illustrates the precision of tracking which is possible at times.

Entomological background.—The invasion by the small mottled willow moth took place on 6 May 1962 in southern England on a scale which has not been observed since records started in 1824. Nearly 1200 moths were counted from May to early November, with the highest individual total of around 100 at Brockenhurst, Hampshire, on 6 May; the previous highest annual count since at least 1930 was 300 in 1938, and in some years none were found.

Mr. R. A. French of Rothamsted, who has assembled these data, considered that the evidence was of arrival in the mid-evening of the 6th in south Hampshire, the Brockenhurst report suggesting a time of about 2100 GMT. Counts of these moths are governed by the existence of enthusiast c amateur entomologists, and the quite good network along southern England generally, strongly suggested west Hampshire as being the main arrival area, with fringe attack as far east and west as Kent and Cornwall. Subsequent catches were probably from the spreading out of the invasion of the 6th, either from the same batch, or with succeeding generations of these moths. There were relatively big catches too in Holland (the only other country in north-west Europe with a comparable observing network). The type of light trap in use is shown in Figure 1, and on Plate II is a photograph of an actual trap.

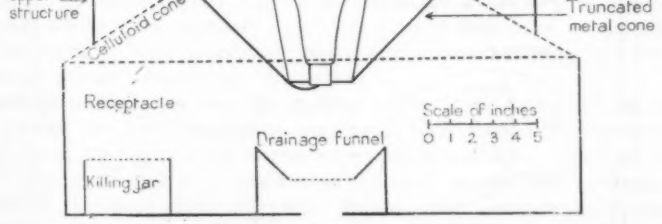

FIGURE 1—DIAGRAMMATIC CROSS-SECTION OF LIGHT TRAP

Analysis.—The moths were believed by Mr. French to have originated from southern Spain or North Africa, and an approximate back-cast was made starting from south-west Hampshire at 2100 GMT, 6 May. This led back to somewhere west of the Straits of Gibraltar two days earlier, so examination was made of the wind and weather conditions in the area from Cape St. Vincent to Agadir. It was found that north-west Africa was the only place

of departure, and the 2nd was the only time of departure reasonably in keeping with observations of wind and the general synoptic pattern. On that date a ridge extended from the south-west towards Spain, and east or north-east winds were blowing along much of the Moroccan coast on the afternoon of the 2nd. Insects such as moths are very much at the mercy of air currents and any altitude reached (above a relatively few feet) would be the result of vertical air motion. In fact, with the maximum temperatures which obtained on the 2nd, vertical currents to around 4000 feet could be expected from the Kenitra radiosonde ascent, so it is reasonable to envisage the moths leaving the African coast at that height. Insects can accept considerable pressure changes, and limitations on height are mainly imposed by temperature.

It will be noted from Figure 2 that the track passes near to both north-west

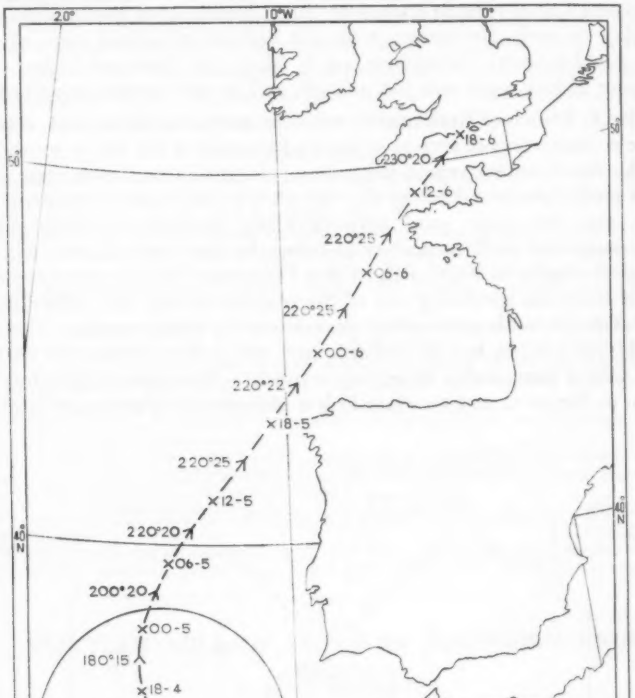

FIGURE 2—BACK-CAST OF FLIGHT OF LAPHYGMA EX.GUA 2–6 MAY 1962
x———x Flight track with time-date on right and wind directions and speeds (knots) on left.

France and north-west Spain, and the possibility cannot be disregarded on meteorological grounds that the moths came from one of these sources, though both are thought very unlikely entomologically. A further consideration militates against these possible sources, that of distribution in England. Had either of these places been the source, distribution in southern England would probably have taken the form of a maximum catch in some definite area, with abrupt fall-off to the west (fetching from off the departure coast), and a much less abrupt decline to the east, as the population in the north-west continent would have been assumed to spread out somewhat west to east; in fact, catches in Sussex and south Kent proved similar in the event to those in Devon and Cornwall. Departure from places well east of Brest or Corunna would vitiate this argument, but distances from the back-cast would become considerably greater.

Having determined departure date, place and height with fair accuracy, a back-cast was made from Hampshire, working on six-hourly intervals between main synoptic surface charts, and this is shown in Figure 2; the circle round the 1200 GMT, 4 May fix is an indication of the magnitude of possible error, taking 2 knots as the order of any such error. The assumption was made that there was a gradual fall of height throughout the flight from 4000 feet to the surface, and this may well not have been so; there was little in the way of ascending or descending air currents after the initial lift, so it may be that the moths relatively soon glided to near the surface, not much above the sea. The airstream was fairly homogeneous, however, and not much error would have been introduced if this did in fact occur. Trajectory winds were calculated from the isobars on the surface chart, with such support as was available from upper wind soundings.

The back track could not be continued beyond about 1200 GMT, 4 May with reasonable accuracy as winds by then were light and variable. However, by assuming departure from North Africa at midday on the 2nd, an estimated position was obtained for 1200 on the 3rd which would be within 200 miles of that obtained by back tracking from England. In this period of 24 hours from 1200 GMT, 3–4 May it is impossible to state winds with any conviction because of the uncertainty of the meteorological situation, and also the lack of data, but the further carry west-north-west of the moths seems very reasonable. The above casts assumed a northward contribution of about 2 knots from the moths as their migratory effort, and a rather bigger 24-hour gap would have existed without this assumption.

Flight as undertaken by the moths.—The exact source of the moths is not known, and meteorologically they could have started from almost any part of north-west Africa, as winds were rather variable. They probably left Morocco at or soon after midday on the 2nd, having been carried up to a height not exceeding about 4000 feet. Initially they were carried westwards on the southern flank of a ridge extending from the Canaries towards southern Spain and Portugal. Skies were well broken, and temperatures ranged from rather above 20°C at the surface to about 13°C at 4000 feet. By the 4th more pattern was obvious on the surface charts, and a small anticyclone in the Madeira area was moving east to north-east soon bringing the moths into a more southerly airstream, although still with clear weather. By the morning of the 5th, the anticyclone had reached Portugal, and the moths were now moving north-eastwards and soon became affected by the stronger south-

westerly winds associated with the Atlantic depression and secondaries west and to the south-west of the British Isles. During the day the cloud increased fairly quickly, though its base was probably in excess of 2000 feet all day. Moth height by midnight was probably below 2000 feet assuming that moisture and blanketing of cloud were to be avoided. During the late afternoon the plotted track passed about 50 miles off Finisterre, and a landfall by at least some of the moths was likely, as the front of flight may well have been broad, with part of it crossing north-west Spain.

On the 6th, the relative humidity continued to rise as more definite cyclonic weather was approached, and across the Bay of Biscay the track moved into the warm sector of a depression west of Ireland, with a waving cold front towards the Azores. Cloud base fell quickly and by dawn the cloud base would probably have been a few hundred feet with patches of sea fog below. The track would just have missed Brittany in mid-morning. Some of the mass flight must, therefore, have crossed the north-west French coast and some doubtless landed; the low cloud and drizzle, however, may well have masked the ground below. Winds were of the order of 25 knots so that unless fairly low already, moths would probably have been swept across to the Channel as they were trying to descend.

The last leg of the flight was over a channel covered by low cloud with mist or fog patches present and light rain or drizzle in places. No doubt the moths were still descending and would probably be crossing at a low altitude, thus there were catches on the south coast of both Devon and Kent on the 6th. Temperatures were about 11–12°C with very humid air.

Catches were also made in Holland, with numbers of the order of 13 on 7 May and 7 on 8 May. These would be reasonably consistent with a continuation of the same trajectory for a further 12 hours or so; one isolated moth was caught on the 5th, but it may be that this was an incorrect identification as it is difficult to see how the mass invasion could have been beaten by 36 hours.

Conclusion.—The large numbers of small mottled willow moths found in southern England in the evening of 6 May 1962 are consistent with a departure of moths from the Morocco coast near or south of Rabat-Salé, some four days earlier. The track which was followed by the moths was almost entirely over the sea and remote from land; an opportunity of landing did exist for some members of the mass flight, and advantage of this was no doubt taken by many moths in landing in north-west Spain and north-west France. As far as others were concerned, however, their first landfall since sunny Morocco was the dull, drizzly south coast of England, and no doubt many regretted their flight.

Acknowledgements.—The author is grateful for the advice and information on entomological matters given by Dr. C. G. Johnson and Mr. R. A. French of Rothamsted.

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551.509.317:551.509.326

A FURTHER DEVELOPMENT OF THE INSTABILITY INDEX

By G. J. Jefferson, M.Sc.

In a previous article[1] an improved form of an instability index suggested originally by Rackliff [2] was described. The modified formula was:

$$T_J = 1.6\ \theta_{w900} - T_{500} - 11, \qquad \ldots \quad (1)$$

where θ_{w900} = the wet-bulb potential temperature at 900 mb and T_{500} = air temperature at 500 mb. This is an improvement on the original Rackliff formula since T_J depends only on the stability and not on the general temperature level of the air mass thus allowing its application to wider areas and all seasons. Tests have however suggested that further improvement is possible.

At London (Heathrow) Airport maps of the distribution of T_J have been drawn covering Europe and the Mediterranean. Experience has shown that while thunder has not occurred in areas where T_J is low, the occurrence of above threshold values by no means always coincides with an outbreak of thundery activity, especially in the Mediterranean. An examination of tephigrams from the areas concerned at once revealed the cause to be the presence of very dry air in the middle levels between 900 mb and 500 mb. An example of an ascent like this is shown for Palma, Majorca in Figure 1 where $T_J = 32$.

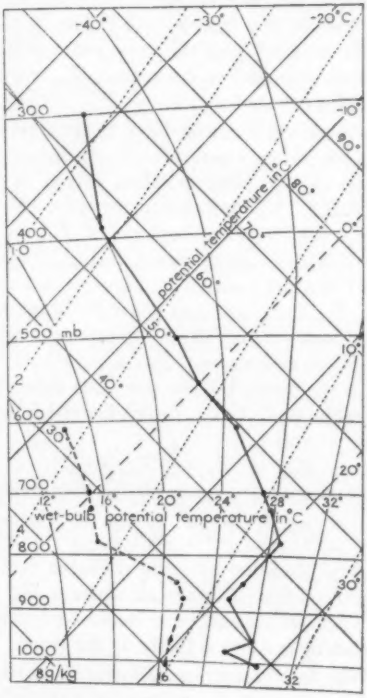

FIGURE 1—TEPHIGRAM FOR PALMA, MAJORCA, 1200 GMT, 11 JULY 1962
——— dry-bulb temperature - - - - dew-point
$T_J = 32$, $T_{mJ} = 27.5$

It was felt that it would be useful if the formula could be further modified to give an index which would allow for this so that a high value would always indicate a high probability of thunder. High-level thundery activity which is common in the Mediterranean area presents a different problem in forecasting from the air mass or frontal thunderstorms of northern and central Europe. The base of the thunder cloud (castellanus or high-level cumulonimbus) is often about 10,000 ft ($\simeq$ 700 mb). The humidity at the base of such a layer must be an important determining factor in the formation of convection cloud. Ideally, in this case, an instability index should be evaluated using θ_w for a level much higher than 900 mb. It would, of course, be difficult if not impossible to construct a map of isopleths of instability index to allow, in this way, for high-level convection in some places while still retaining $\theta_{w_{900}}$ in others. Since convectional activity originating at lower levels is also seriously hindered by the entrainment of very dry air at levels above 900 mb, it is evident that the humidity of the air is an important factor in both cases. The 700 mb level, midway (in pressure) between the levels of the two parameters already in use, has been used to modify the formula as follows:

$$T_{mJ} = 1.6\ \theta_{w_{900}} - T_{500} - \tfrac{1}{2}T_{d_{700}} - 8, \qquad \ldots \quad (2)$$

where the additional parameter $T_{d_{700}}$ is the dew-point depression in °C at 700 mb. Like the others, this is easily read from the tephigram. The factor of $\frac{1}{2}$ was introduced to avoid too heavy a weighting of the index by $T_{d_{700}}$. It will be seen that this formula will give the same index as T_J when $T_{d_{700}} = 6$°C. When the air at 700 mb approaches saturation, T_{mJ} will be increased a little (by a maximum of 3 for saturated air).

Some trials of this modified formula have been made and they show that areas of high T_J with no indication of thunderstorm activity are satisfactorily eliminated. The value of T_{mJ} for the Palma ascent in Figure 1 is $27\frac{1}{2}$, i.e. below the threshold value. No thunderstorms were recorded in the area as can be seen in Figure 2 which shows isopleths of T_{mJ} on that date as well as plots of thunderstorms. This example shows that areas of high T_{mJ} correspond quite well with area of thundery activity. Figure 3 is a recent example which shows isopleths of T_{mJ} for 1200 GMT and plots of thunderstorms for 1200 and 1500 GMT on 27 April 1963. The close correspondence between the two is again quite evident. It would appear that a threshold value of 28 or 29 is more satisfactory than 30 given by the previous formulae. T_{mJ} cannot be evaluated quite so quickly as T_J but is easily derived from it.

From equation (1) and (2)

$$T_{mJ} = T_J - (\tfrac{1}{2}T_{d_{700}} - 3),$$

which leads to the following correction table for converting T_J to T_{mJ}:

$T_{d_{700}}$	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
Correction to T_J	+3	+2	+1	0	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10	−11	−12

In this way T_{mJ} can be obtained by using the table previously given for T_J.[1] When T_{mJ} has been plotted for all upper air stations for the area being considered, isopleths of 28 are drawn and these may be expected to show the limits of the area where thundery activity is likely at the time.

In using maps of T_{mJ} for forecasting, allowance must of course be made for advection. When a chart of T_{mJ} based on midnight ascents is used for forecasting the likelihood of thunder in the period of maximum activity in the following afternoon and evening, allowance can also be made for surface

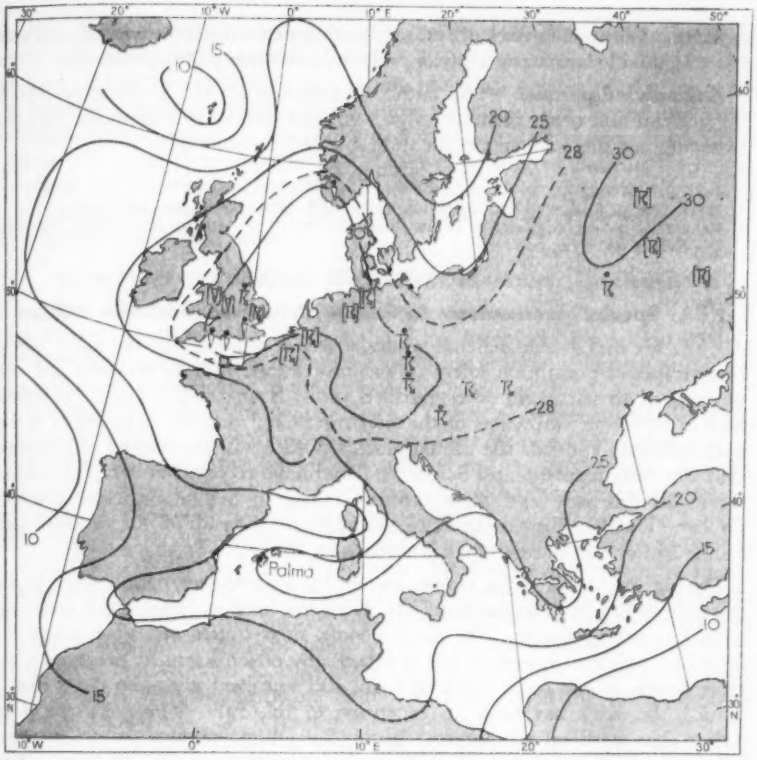

FIGURE 2—ISOPLETHS FOR T_{mJ}, 1200 GMT, 11 JULY 1962
Plots of showers and thunderstorms are for 1500 and 1800 GMT. Weather in the past hour is shown in brackets.

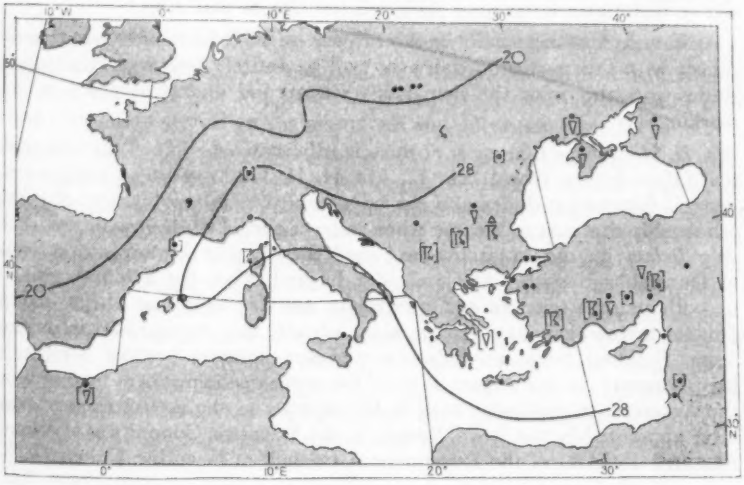

FIGURE 3—ISOPLETHS FOR T_{mJ} FOR 1200 GMT, 27 APRIL 1962
Plots of precipitation and thunderstorms are for 1200 and 1500 GMT. Weather in the past hour is shown in brackets.

heating. When the effect of surface heating extends above 900 mb the value of θ_{w900} will show some increases which in its turn will increase T_{mJ}.

Acknowledgement.—The author is indebted to Mr. B. Ramsey, Mr. D. T. J. Dean and other members of the forecast staff at Heathrow for their help in trying out this further modification on the forecast bench.

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2. RACKLIFF, P. G.; Application of an instability index to regional forecasting. *Met. Mag., London*, **91**, 1962, p. 113.

NOTES AND NEWS

Special promotions to Senior Principal Scientific Officer

Mr. T. H. Kirk.—The scheme whereby a few scientists in the Civil Service receive special promotion solely on account of their individual merit and without regard to vacancies or established posts, is one of the more enlightened aspects of the organization of the Scientific Civil Service. His many friends both inside and outside the Meteorological Office will have heard with pleasure that the Interdepartmental Scientific Panel have recognized Mr. T. H. Kirk's merits in this way and have promoted him to Senior Principal Scientific Officer. On behalf of the Director-General and the staff of the Meteorological Office I offer our sincere congratulations to Mr. Kirk on this award.

During the whole of his career, except for a three-year period when he was engaged in marine meteorology, Mr. Kirk has been engaged on or concerned with forecasting duties. For most people such duties are so exacting that little or no time or energy is left to attack any of the scientific problems which have arisen in the day's work and are still unsolved after the day's work is done. Mr. Kirk has been an exception to this rule. The problems of the day-to-day work on the forecast bench have inspired him to seek practical solutions which can be applied in similar circumstances in the future. Both during the war and during the last six years he has been responsible for major forecasting units in the Mediterranean and has made full use of his opportunities to investigate forecasting problems peculiar to that area.

It is very fortunate that, in the future, we shall have the assistance of an officer with this particular flair who will be entirely free from administration duties and also from the demands on time and energy imposed by roster working. A.C.B.

Mr. H. H. Lamb.—Like most of the scientific staff who joined the Meteorological Office before World War II, Mr. H. H. Lamb spent his early years on general forecasting duties and the opportunity to follow his natural bent for scholarship and research came when, after a period of duty with the whaling ship *Balaena* in the Antarctic, he joined the division for forecasting research at Dunstable in 1948. At Cambridge he had taken the Tripos examination in both natural sciences and geography and his work has always shown a flair for meteorology as a geographical science, that is geophysics in its proper sense. Building upon his *Balaena* experience he soon became a recognized British expert on the meteorology of the southern hemisphere in general and the Antarctic in particular and, in his capacity as the meteorology representative appointed by the Royal Society to the Scientific Committee on Antarctic Research (SCAR) of the International Council of Scientific Unions (ICSU),

his special knowledge in this field is still valued. His main interest in more recent years has moved in another direction, to the variation of climate through the ages and especially during the recent historical period. Once more he has become a national figure in his chosen subject with many important published papers already to his credit and it is here that we expect his main work to lie for some time to come. Mr. Lamb is the kind of dedicated scientist for whom the scheme of promotion on special individual merit might well have been invented and we may be confident that he will repay with continuing scholarship of a high order. R.C.S.

Open Days at the Royal Radar Establishment, Malvern

The Royal Radar Establishment (RRE) at Malvern held a series of Open Days from 21–25 May 1963, the first that have been held since 1948. There were more than 2000 visiting scientists on the first four days, and an estimated 10,000 'families and friends' of the staff on the last day.

The Research Unit of the Meteorological Office at Malvern and the RRE group with which it is working on the application of radar techniques to meteorology, took an active part in the exhibits and demonstrations. A series of 30 display cards described the techniques used and some of the meteorological results obtained with a fixed 3 cm-wavelength Doppler radar and a high-resolution 8.6 mm pulsed radar. It was shown how the Doppler radar has been used to study the variation of drop-size distribution with height in steady rain, to determine vertical air motions within showers, and to measure small-scale variations of wind from the motion of precipitation particles in warm-front rain belts. The 8.6 mm radar has been used to study the fine structure in precipitation and clouds. Visitors were also shown a working display on a mobile 3 cm Doppler radar which is designed to extend the range of study to thunderstorms.

The Meteorological Research Unit also contributed a special exhibit to the main information centre in Nelson Hall at RRE. It consisted of a display panel, 30 feet in lenght, of the percipitation pattern through a cold front (see Plate V facing p. 303). W. G. HARPER

The Meteorological Office at the National Gliding Championships

During the period of the National Gliding Championships held at Lasham, Hampshire, from 25 May to 3 June 1963, a mobile meteorological office provided a forecasting service for the organizers and pilots (see Plate III).

One of the primary tasks of the meteorologists was to participate in task-setting each morning by providing the organisers with a detailed survey of the expected distribution of cloud, wind, and thermal conditions over the southern half of England, so that tasks for the eighty competing gliders could be chosen—tasks which would exploit the weather potential and test the skill of the pilots, yet which were neither too easy nor impossible. Detailed briefings of weather conditions over the selected routes were given at mass gatherings of pilots and crews each morning and discussions on the tactical use of the expected weather continued during the contest departures. Some glider pilots are now able to use conditions which a few years ago would have been regarded as prohibitive, and meteorologists have gained further insight into the structure and development of micro- and meso-scale weather systems.

J.F.

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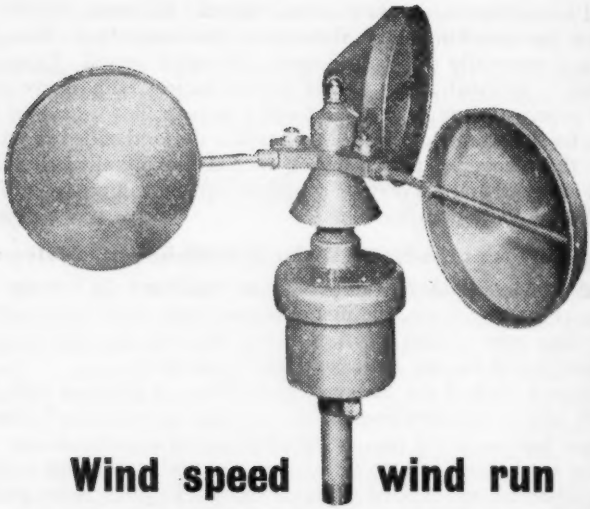
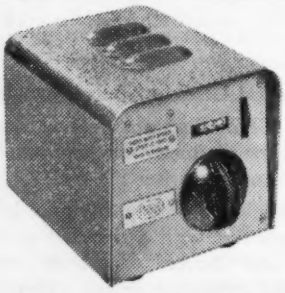


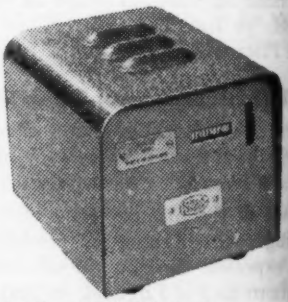
Wind speed wind run

Observed remotely indoors & in comfort

The new range of Casella Anemometers and Digital Read-out Indicators permit the "10 minute average wind speed" and "the total run-of-wind" to be read indoors at any reasonable distance from the Anemometer head. Thus the recommendations of the WMO can now be followed accurately and simply. Illustrated is the new electric contact pattern. Also available is a new totalising pattern with a sloping, easy-to-read indicator panel. Each gives long life with minimum servicing.



10 min. Average Wind Speed Indicator
Two models—one with a manually operated timer to set the indicator working at any given moment—the other an automatic model ten-minute average wind speed indicated every hour. Speed in knots and miles or kilometres per hour, depending on the Anemometer used.



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This remote indicator overcomes the disadvantages of the conventional totalising Anemometer. It is no longer necessary to use binoculars or climb the mast to observe the instrument reading. This information can now be read in the comfort of your office.

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